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ANNOTATED BIBLIOGRAPHY ON THE EFFECTS OF IRRIGATION PRACTICES ON STREAM WATER QUALITY WITH EMPHASIS ON SALINITY AND PESTICIDES

Public Health Service
Denver, Colorado

November 1963

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U. S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
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U. S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service
Bureau of State Services
Division of Water Supply and Pollution Control
Region VIII

Colorado River Basin Water Quality Control Project

November 1963

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PREFACE

Salinity is one of the largest single contributors to pollution of waters in the United States, particularly in the 17 western states where practically all of the irrigated acreage exists. Surveys in several river basins in the 17 western states have shown that the levels of salinity are above desirable limits for many legitimate water uses, and that a portion of the salinity increase is caused by irrigation practices. The term salinity is synonymous with total dissolved solids (TDS) when it is used with reference to irrigation practices and water quality. The solids are usually and most predominately the bicarbonates, sulfates, and chlorides of calcium, magnesium, and sodium. The popular conception of salinity is restricted to the salts of chlorides, particularly sodium chloride (table salt), and it takes a while to adjust to the more inclusive definition.

The obvious broad classifications for sources of salinity contribution to surface flows are: (a) natural and (b) man-caused. The natural sources, such as the introduction of salts to surface flows through springs and the concentration of salts through evaporation and transpiration, as well as others, undoubtedly have a large effect on the salinity of surface flows as well as ground water flows. The purpose of this bibliography, however, is to accumulate information on the effects of irrigation practices on water quality, because irrigation agriculture is presumed to be the man-caused source of salinity that exerts the largest influence on total basin-wide salinity. In a U. S. Department of Interior report, the Geological Survey indicates that presumably about 99 percent of the man-caused total dissolved solids discharging from the Upper Colorado River Basin are an effect of irrigation[1/].

One of the broad objectives of the Colorado River Basin Project is to predict water quality conditions which would be expected with no salinity reduction measures in effect, for comparison with expected water quality conditions that assume the feasible control measures were put into effect.

It was considered essential to obtain or develop information in the form of an annotated bibliography pertaining to the effects of irrigation practices on water quality prior to the inception of a basin-wide salinity study. No sizable compilation on the subject could be found; therefore, the following work was undertaken. Since the use of pesticides is intimately associated with agriculture, and since pesticides are of interest in water quality studies in the Colorado River Basin from the standpoint of salinity as well as toxicity, a section of the bibliography is devoted to the effects of pesticides on water quality.

1/ Quality of Water, Upper Colorado River Basin, Progress Report. U. S. Geological Survey and U. S. Bureau of Reclamation (Jan. 1963).

INTRODUCTION

In the arid West, irrigation agriculture is a necessity of life, and throughout the Colorado River Basin significant acreages are utilized for this purpose. In any irrigated area, the maintenance of a favorable salt balance is essential to the continued productivity of that area. When this balance is maintained, the total weight of dissolved constituents leaving a given irrigated area via surface and subsurface drainage is equal to or greater than the total weight diverted into that area. The effect of salinity contribution from such drainage to the receiving waters will be determined by many variables including the size and character of the receiving body.

When nutrient and pesticide chemicals are present in the drainage waters as well, the subsequent effect may be more significant.

The purpose of this bibliography is to provide information of a general nature concerning the mechanics, variables, and effects of the introduction of saline materials stemming from agricultural activities into receiving waters. It is hoped that the publication of this listing will furnish a reference base which interested persons may use in the exploration of this subject.

The references in this work have been compiled from a variety of sources including periodicals, published abstracts, and government and university publications.

This document is not meant to be a finished reference list but merely a good beginning. The enclosed listing is presently exclusive of many subject items pertaining to irrigation agriculture such as economics, soil mechanics and chemistry, application methods, etc., and is restricted to the subject items more directly related to effecting a water quality degradation. The Project intends to expand these individual subject items by material reviewed by Project personnel and from contributions by interested persons.

At this time, the bibliography is divided into six sections by subject. It was decided to limit the initial material search to selected subjects and expand the coverage of subjects as time allowed at a later date.

It is hoped that interested persons will contribute references on the subject to the Colorado River Basin Project office for inclusion in this compilation. When the Project receives or reviews a substantial number of additional references, it will publish an enlarged and expanded compilation of this subject matter.

I RETURN FLOW EFFECTS ON WATER QUALITY

The primary interest of water pollution control agencies concerned with salinity is voiced in this section. Tastes and odors, algal growth from added nutrients, undesirable high levels of total dissolved solids, thermal pollution, high turbidity, high nitrates, excessive hardness, deteriorated sanitary quality, levels of concentration of agricultural poisons toxic to fish--these and other quality deteriorations have been attributed to agricultural drainage in many instances. The effect of salt contributions from such drainage will be determined by many variables including the size and character of the receiving body of water.

There is not a large volume of material available on this specific subject to date, apparently because of only recent interest in water quality degradation by agricultural return flows.

1. Scofield, C. S., Salt Content of Colorado River Increased in 25 Years. Engineering News-Record, Vol. 97, 4, p. 131-132 (July 22, 1926).

   Chemical analyses of Colorado River water are given for 3 yearly periods from October 1, 1922 to September 30, 1925. Some similar data for the years 1900 and 1905 are also given.

   For the three yearly periods, the salt content (total dissolved solids) ranged from 210 to 1250 mg/l, the three yearly means being 896, 839, and 997 mg/l respectively. The average hardness as calcium carbonate for the three-year period was 260 mg/l. The mean salt content for the years 1900 and 1905 were 713 and 723 mg/l respectively.

2. Debler, E. B., Return Flow and Its Problems on Reclamation Projects. New Reclamation Era, Vol. 18, 8, p. 124-125 (August 1927).

   Salts liberated from soils are removed almost as fast as they become available in areas of ample precipitation. However, in the arid regions, highly mineralized soils occur due to insufficient moisture to remove the liberated salts. The drainage from such soils is often highly charged with salts. Streams which pass through the arid regions increase in mineral content due to the influx of this more highly charged water, plus salt concentration in the stream itself due to evaporation losses. When these stream waters are used for irrigation, only a negligible amount of the salts carried in the applied water are removed by the irrigated crops. The salt content of the water evaporated by the soil and crops is left behind in the soil. If irrigation is to continue indefinitely the residual salts

of a deleterious character must be added to the salt content of the water discharging as return flow. In its percolation through the soil the return flow has further opportunity to become heavily charged with salts. Chemical combination of dissolved salts with others in situ on the land may occur forming either harmful or beneficial insoluble precipitates. The character and concentration of the dissolved salts in return flow water determine the suitability of such water for irrigation purposes as indicated by crop tolerances.

3. Hill, R. A., Salts in Irrigation Water. Proceedings American Society Civil Engineers, Vol. 67, 6, p. 975-990 (June 1941).

The writer has developed a geochemical chart to be used in classification of natural waters for irrigation use. The need for classification of irrigation waters has grown out of the tendency for irrigation engineers to disregard the character and constituents of irrigation waters other than consideration of the total dissolved solids. The author has found the chart useful in classification and for the solution of problems arising with mixtures of water and with quality changes resulting from irrigation.

4. Scofield, C. S., Trends of Irrigation Development in the United States. Chemical and Engineering News, Vol. 29, 11, p. 990-994 (March 1951).

In each of our arid drainage basins, the drainage from irrigation areas is discharged back into the stream from which the water was diverted. This return flow is higher in salt concentration and smaller in volume than the upstream diversion. Successive diversions and drainage returns have the cumulative effect of increasing the salt concentration in the downstream direction. This cumulative effect calls for larger allocations of water to provide larger volumes of applied water for salt removal from the downstream projects.

5. Howard, C. S., Irrigation and Water Quality: Part I - How Dissolved Solids Increase in Irrigation Water. The Reclamation Era, Vol. 39, 1, p. 1-2 (January 1953)

Drains must be provided to carry the residual salts left by irrigation water out of the root zone to avoid a toxic accumulation of soluble solids. The annual use of 2.5 acre-ft. of water like the Colorado River below Hoover Dam, for example, will make available more than 2 tons of soluble salts per irrigated acre. This tonnage of salts must be carried from the land via drainage water for sustained production to occur. In this way, plus natural salinization, large quantities of soluble material may be added to the salt load of a stream.

6. Howard, C. S., Irrigation and Water Quality, Part II - Quality of Water in Selected Basins. The Reclamation Era, Vol. 39, 2, p. 39-40 (February 1953).

This paper is a discussion of the return-flow pollution problem in irrigated areas and the probable future aggravation of the problem by increased irrigation. The author points out that in addition to river flow regulation, Hoover Dam also regulates water quality for the downstream users. Because much of the irrigation in the Lower Basin of the Colorado is done at a time when the normal stream flow is lowest and the mineral content is highest, the quality of irrigation water from the unregulated stream would be relatively poor. Lake Mead storage has provided a fairly uniform dissolved solids concentration and the Lower Basin irrigators are now applying water with a lower average dissolved solids concentration than the water they had prior to river regulation.

7. Beacher, Bruce F., Don't Gamble with Water Quality. The Reclamation Era, Vol. 39, 3, p. 56-58 (March 1953).

This paper is concerned principally with water quality for irrigation use. The following pertinent facts are mentioned:

a. The soil water in an irrigated area may become as much as 10 to 100 times higher in salt content than the applied water.

b. Return flows in many places must be diluted by a factor of 10 or more for safety in subsequent irrigation use.

c. Sodium is the major element involved with the occurrence of black alkali and poor drainage.

8. Flaigg, N. G., The Effect of Irrigation and Return Flow on Water Supplies. Southwest Water Works Journal, Vol. 34, 12, p. 9-16 (March 1953).

Return flow from an irrigation project contains an increased concentration of minerals and a change in constituents, depending upon many factors. This paper states that the effect of use of herbicides and insecticides in not adequately known.

9. Report of Progress, 1938-1953. U. S. Dept. of Agriculture, U. S. Salinity Laboratory, Riverside, Calif., 38 p., (July 1953).

In a section titled, "Changes in Quality of Water," this report cites examples to illustrate there is a problem of water quality degradation from irrigation return flows. Such degradation can be demonstrated from the records of the laboratory.

There are many diversions and drainage returns along the Rio Grande near the Colorado-New Mexico State line and Fort Quitman, Texas. Only one-tenth of the water passing a point near the State line reaches Fort Quitman but the salt content increases from the State line from 200 mg/l to 2600 mg/l at Fort Quitman. The laboratory has calculated salt balances for the following projects: Rio Grande, Yuma, Wapato, Sunnyside, Sutter Basin.

10. Cunningham, M. B., et al, Effect of Irrigation Runoff on Surface Water Supplies. Journal American Water Works Association, Vol. 45, 11, p. 1159-1179 (November 1953).

Irrigation statistics are give on acreage, irrigation growth, and the problems inherent in maintaining a favorable salt balance.

Some studies indicate that at least 10 percent of the water applied to the soil should go on through as drainage water to leach salts. Examples of water quality affected by irrigation residues are given.

11. Silvey, J. K., Relation of Irrigation Runoff to Tastes and Odors. Journal American Water Works Association, Vol. 45, 11, p. 1179-1186 (November 1953).

The author suggests that the major cause of tastes and odors in water supplies is the association of actinomycetes and algae in different stages.

The article concludes that irrigation return flows containing phosphates and inorganic nitrogen will increase the frequency of occurrence of tastes and odors in surface water supplies.

12. Wilcox, L. V., Irrigation Water Quality as Affected by Use and Reuse. Chemical and Engineering News, Vol. 31, 3, p. 3454 (1953).

The quality of a water for irrigation use is determined by the character and concentration of its dissolved constituents. These constituents affect the chemical and physical properties of the soil and crop growth. The more important characteristics of a water for irrigation use are:

a. Concentration of total dissolved solids. A high concentration leads to soil salinity conditions and interference with crop production.

b. Sodium content. A high sodium content may result in alkali formation.

c. Bicarbonate content. Bicarbonate ions will react with dibasic cations.

d. Boron content. Boron may occur in concentrations toxic to plants.

The principal effects of use and reuse of irrigation waters are:

a. Total dissolved solids increase.

b. Precipitation of sulfate, bicarbonate, magnesium, and calcium.

c. Sodium concentration increase and often an increase in total quantity.

13. Swenson, H. A. Irrigation Runoff as a Factor in Water Quality. Presented before the 14th meeting of the Subcommittee on Water Supply and Water Pollution Control, Columbia Basin Interagency Committee, Olympia, Washington (May 1, 1957).

Progressive increases in concentrations of soluble salts in the downstream direction are shown by streams receiving drainage from irrigated land. This progressive increase has been observed in the Rio Grande, Poudre, San Joaquin, Boise, Arkansas and Yakima Rivers and many others.

This stream water quality deterioration has in recent years received increased attention. Water distribution compacts in the future will undoubtedly consider this factor. For example, a present contract between the Contra Costa County District, California, and the U. S. Bureau of Reclamation provides that the district does not have to accept or pay for water containing more than 250 mg/l chloride.

14. Wilcox, L. V., Discharge and Salt Burden of the Rio Grande above Fort Quitman, Texas, and Salt- Balance Conditions of the Rio Grande Project for the Year 1956. U. S. Salinity Laboratory Research Report No. 85, 26 p., U. S. Department of Agriculture (November 1957).

This is the Salinity Laboratory's annual report of discharge and salt burden above Fort Quitman, Texas and salt-balance conditions of the Rio Grande Project for the year 1956.

The discharge of the Rio Grande for 1956 was lower than any year for the period of record (from 1890). The total discharge at Fort Quitman, about 60 miles below El Paso, was only 3 percent of the 1934-1956 average of 177,866 acre-feet.

The chemical composition and concentration data of the water in the river is given above and below 3 irrigation projects' diversion points and drainage returns. These data show that the total concentration, percent, sodium and the concentration of practically all the ions increased progressively in the downstream order from Otowi Bridge to El Paso, as in years past. The tonnage of salts crossing the El Paso-Hudspeth County Line, about 40 miles below El Paso, was only 0.12 percent of the tonnage below Caballo Dam.

The salt-balance conditions were found to be highly unfavorable in all three divisions of the Rio Grande Project.

15. Wright, C. T., Water Quality in the Upper Colorado River Basin and Its Relation to Reclamation Projects. U. S. Public Health Service, Salt Lake City, Utah, 38 p., (1958).

In the Upper Colorado River Basin, depletion of streamflow by irrigation increased the total dissolved solids concentration appreciably, (approximately 15 percent up to 1955). Other contributing factors are evaporation, diversions (transmountain), and the leaching of salts from irrigated land to maintain a favorable salt balance. Studies are recommended throughout the Basin including "a complete report on the effects of return flow from the standpoint of chemical quality..."

Numerous graphs showing discharge and chemical quality for 23 stations in the Upper Basin (1948-1955) are included.

Considerable variation in the effects of irrigation return flow on water quality is to be expected. The factors include: size of irrigated areas, number of times water is used, properties of soils, age of irrigation project, nature of aquifers, rainfall, dilutions, temperature, irrigation practices, and storage reservoirs.

Total dissolved solids concentrations in return flows in the absence of salt accumulation from ground water is increased from about 2 to 10 times the concentration of salts in the applied irrigation water.

16. Eldridge, E. F., Return Irrigation Water--Characteristics and Effects. U. S. Public Health Service, Portland, Oregon, 120 p., (May 1960)

This paper demonstrates, by referring to published material, that irrigation return flows have a pronounced effect on the quality of surface and ground waters in a considerable portion of this country. This investigation has shown that potential water quality problems involve many different factors; namely, changes in salinity, hardness,

temperature, turbidity, nutrients and aquatic growths, odor and taste, nitrates, and sanitary quality. The actual and potential effects of each of these factors on water uses are analyzed. Major water uses considered are domestic and industrial water supply, recreation, fisheries, and irrigation.

17. Eldridge, E. F., The Effect of Irrigation on the Quality of Water for Industrial Use. Proceedings 14th Purdue Industrial Waste Conference, p. 52-67 (September 1960)

Irrigation return flows contain as much and usually more dissolved solids than the stream from which it came, resulting in substantial increases in salinity and hardness. Problems of softening, salty taste, and pollution by organisms are presented. The solution of the problem lies in fundamental long-range planning of waste use for agriculture, domestic, and industrial uses.

18. Hoak, R. D., The Thermal Pollution Problem. Journal Water Pollution Control Federation, Vol. 33, 12, p. 1267-1276 (December 1961) .

The effect of stream temperature regulation on fish life is discussed in this paper. Water use priorities and their relation to the recreation industry are considered along with dissolved oxygen and temperature, diurnal changes in dissolved oxygen, and pollutional loadings. The data is analyzed with reference to Pennsylvania.

19. Engelbrecht, R. S. and Morgan, J. J., Land Drainage as a Source of Phosphorus in Illinois Surface Waters. Algae and Metropolitan Wastes Transactions of the 1960 Seminar, Taft Sanitary Engr. Center, Technical Report, W61-3, p. 74-79 (1961).

The major sources of phosphate substances in surface waters are human wastes, chemicals employed in water conditioning, synthetic detergents, industrial wastes, and drainage of agricultural lands.

This paper discusses some of the factors that bring about various concentration of phosphates in the drainage water from agricultural land and presents the results of stream surveys of several Illinois surface waters, in particular, the Kaskaskia River. These studies demonstrate the importance of land drainage as a source of orthophosphate, hydrolyzable phosphate, and organic phosphate in streams that drain highly cultivated lands.

20. Sylvester, Robert O., Nutrient Content of Drainage Water from Forested, Urban, and Agricultural Areas. Ibid., p. 80-87.

Field observation of nutrition concentrations are presented for drainage waters originating in timbered areas of little habitation and land use; urban street drainage; subsurface and surface drains carrying irrigation return flows; and urban streams. The effect of land and water use on nutrient concentration is clearly shown.

21. Wilcox, Lloyd V., Salinity Caused by Irrigation. Journal American Water Works Association, Vol. 54, 2, p. 217-222 (February 1962).

Irrigation water brings salt to the land and an equal amount must be removed to prevent an accumulation of salt in the soil. Since the volume of drainage water is seldom more than half of the diverted water, in order to maintain a proper salt balance, the return flow will have to increase in salt concentration. The return of this water can cause pollution problems. If dilution of return flow is great, such as in the Colorado River, little pollution will result. If dilution of drainage is not sufficient, such as in the Rio Grande River, pollution will result.

22. Sylvester, R. O. and Seabloom, R. W., The Character and Significance of Irrigation Return Flows in the Yakima River Basin. University of Washington, Dept. of Civil Engineering (February 1962).

Return flows are that portion of diverted irrigation water that is not lost to evapotranspiration in an irrigated area of stabilized ground-water levels. Return flows contain salts whose concentration has been increased by leaching, evapotranspiration, and ion exchange. Other water quality changes are caused by erosion, filtration, absorption or release of solar radiation. The data provided in this study concerns the effect on the quality of surface and subsurface irrigation return flows by the causes of water quality change listed above and fertilization and crop removal. The following are the major conclusions of the report.

a. Of 6.6 acre-ft/acre of diverted water, 2.35 acre-ft/acre was lost due to canal seepage, evapotranspiration, and wastage.

b. Irrigation effects created a ground water whose salt content was approximately five times that of the adjacent surface waters.

c. Salt concentrations were increased by 1.7 times due to evapotranspiration; however, leaching and ion exchange were the primary phenomena responsible for the increase in the quantity and composition of the salts in the return flow.

d. Increases in chemical constituents due to ion exchange and leaching in the subsurface drains are expressed as number of times greater than in the applied water: bicarbonate alkalinity - 3, chloride - 10, sulfate - 5.5, nitrate - 8, sodium - 7.5, soluble phosphate - 5, and total phosphate - 1.

e. The type of crop, the method of water application, and the fertilizers applied had no marked effect on return flow water quality unless there was over-irrigation or fertilizer application was in excess of crop requirements.

f. Most of the sulfate and sodium in the receiving river was contributed by the return flows, and there was a large loss of nitrates in the drainage system.

II PESTICIDE EFFECTS ON WATER QUALITY

This section is presently oriented only to receiving stream effects from pesticide use in irrigated areas. This section will be expanded in the future to include toxicity information, pesticide classification, and other pertinent pesticide information.

1. Young, L. A. and Nicholson, H. P., Stream Pollution Resulting from the Use of Organic Insecticides. Progressive Fish-Culturist, Vol. 13, 4, p. 193-198 (October 1951).

   In the Tennessee River Valley of Alabama in 1950, fish were killed in large numbers in at least 15 streams. The fish kills were traced to locally used insecticides sprayed or dusted on cotton crops. The insecticides involved included aldren, DDT, benzene, hexachloride, and toxaphene. Several heavy rains occurred prior to the kills.

   The control difficulties and the leaching problems involved with pesticide usage are pointed out.

2. Warrick, L. F., Blitz on Insects Creates Water Problems. Proceeding 6th Purdue Industrial Waste Conference, p. 455-463 (November 1951)

   The scope of the potential stream pollution problem from pesticide usage is indicated by description of a fish kill. In one area, fish kills occurred in 15 streams as an indirect result of using insecticide on cotton crops.

3. Ingram, W. M., Selected Bibliography of Publications Relating to Undesirable Effects upon Aquatic Life by Algicides, Insecticides, Weedicides. U. S. Public Health Service, Public Health Bibliography, Series No. 13, 28 p. (1954).

   The papers which are included in this bibliography contain data on the harmful effects of algicides, insecticides, and weedicides on aquatic organisms other than those which they were designed to control. Another aspect of the problem is that in the use of algicides and weedicides, the destructive action may be delayed or indirect and thus might not be attributed to the control chemicals.

   The decay of algae and higher plants killed by control agents can initiate a cycle of events that may lead, under certain conditions, to the lowering of dissolved oxygen to critical levels which may result in the death of fish and fish food organisms. The bacterial decomposition of algae and aquatic weeds uses up the dissolved oxygen in the water and under such a condition a fish kill may result.

4. Middleton, F. M. and Rosen, A. A., Organic Contaminants Affecting the Quality of Water. Public Health Reports, Vol. 71, 11, p. 1125-1132 (November 1956).

Concentrations of DDT in the range of one to five parts per billion were found in the drinking water of several cities using river water as the source of supply. The insecticide could not be recovered at all times but persisted for a 6-month period in one location. The major source of the DDT was presumed to be spray operation.

Through the widespread agricultural use of DDT, exposure resulting from various sources, particularly food, is much higher than the exposure that could result from ingesting drinking water containing a 5 parts per billion concentration, the estimated maximum level found in the waters examined. Although present levels of such materials as DDT in water may not be significant from the standpoint of human physiological effects, concentrations below 1 part per billion of chlorinated insecticides are toxic to fish. Toxaphene has been reported to be lethal to fish in 10 days at less than 6 parts per billion concentration.

5. Bogan, R. H., Biochemical Degradation Products - A New Dimension in Stream Pollution. Sewage and Industrial Wastes, Vol. 30, 2, p. 208-214 (February 1958).

In view of recent changes in the nature of wastes reaching surface waters, some of the currently accepted practices of measuring stream pollution are examined. Evidence was obtained which indicates that biochemical degradation products might be formed from certain classes of compounds. The biochemical behavior of synthetic detergents, alkanes, high-molecular fatty acids and alcohols, low-molecular ethylene glycols, and alkyl benezenes was studied. Oxidation of an organic compound may be related to only a portion of the original molecule. Through hydrolysis and fission, an organic material may be broken into two or more fragments. Evidence is given that enzyme activity such as fissioning of the C_6H_6 ring may regulate the oxidation rate of a substance. Infrared spectrograms are given of the original test material and of the material remaining after contact with acclimated sludge for a 24-hour period. The spectrograms are considered and analyzed.

6. Nicholson, H. P., Insecticide Pollution of Water Resource: Journal American Water Works Association, Vol. 51, 8, p. 981-986 (August 1959).

Synthetic organic insecticides may be found in lakes and rivers, kill useful water life, and damage water resources. Recorded instances of fish kills by insecticides are given. The effects of insecticides

on humans have not yet been determined with the exception of DDT. This paper proposes a bioassay control method for insecticides using goldfish or other suitable test fish. The stated conclusion is that if the insecticide is not present in concentrations that will kill fish, there will be no significant public health hazard.

7. Rosen, A. A. and Middleton, F. M., Chlorinated Insecticides in Surface Waters. Analytical Chemistry, Vol. 31, 10, p. 1729-1732 (October 1959).

A general monitoring procedure that can detect a variety of common insecticides in concentrations below those toxic to aquatic life is required in surface water quality evaluation. This paper describes the accomplishment of this result through a combination of the processes of carbon filter sampling, adsorption chromatography, and infrared spectrophotometry. This method has proved sufficiently sensitive to make it possible to identify less than 10 parts per billion of eight chlorinated insecticides in river water. The method has been tested with aldrin, chlordane, DDT, dieldrin, methoxychlor, endrin, benzene, hexachloride, and DDD.

8. Tarzwell, Clarence M., Pollutional Effects of Organic Insecticides. Transactions 24th North American Wildlife Conference, p. 132-142 (1959).

Many of the recently developed synthetic organic insecticides are extremely toxic to fishes. Long-term studies have been made of some of these which have shown that as the period of exposure is increased, toxic concentrations become correspondingly smaller. These materials have a long residual toxicity once they have been introduced into the soil and waters. The widespread use of these materials creates an immediate pollution problem.

Studies of each new insecticide to determine the toxicity of runoff and seepage water from various soil types, slopes, and vegetative covers for different dosages, formulations, and modes of treatment should be undertaken. Toxicities to fish for 25 insecticides are given. Also presented are five suggested measures which can be taken to lessen or abate stream pollution due to the use of the new synthetic organic insecticides.

9. Worrell, Albert C., Pests, Pesticides, and People. American Forests Magazine (July 1960).

This paper deals not with the technical features of pesticide use, but with broad social factors which should enter into policies for pesticide use. The paper concludes in noting how difficult it is to judge composite

situations of pecticide use where many different chemicals are being applied year after year in particular areas. Such evaluation is also hampered by serious deficiencies of knowledge regarding the physical and biological effects of pesticides.

10. Bandt, Hans Joachim, Chemical Destruction of Insects and Weeds Poisons Water. Wasserwirtsch-Wassertech Vol. 10, p. 30 (1960)

The increased usage of organic poisons as herbicides and insecticides has increased the problems involved in accidental poisoning of fish. The paper discusses various insecticides in terms of their usage and toxicities to fish.

11. Cohen, Jesse M., et al, Effects of Fish Poisons on Water Supplies, Field Study at Dickinson. Journal American Water Works Association, Vol. 53, 2, p. 233-246 (February 1961).

This study confirmed the fact that treatment with activated carbon will produce a safe and palatable water from a water supply that has been contaminated with fish poison.

12. Cottam, Clarence, Pesticides, Chemicals, and Water Pollution. Public Works, Vol. 92, 6, p. 206-209 (June 1961).

The problems caused by pollution of surface waters by organic chemicals are described. Specific examples of effects on wildlife and crops are also given.

13. Bogan, R. H., et al., Pesticides in Natural Waters. Research Vol. 14, 7, p. 269-274 (July 1961).

Although many pesticides are not very soluble in water, they are nevertheless soluble enough to be toxic to fish and various food organisms. Many major U. S. rivers contain pesticides in concentrations approaching the toxic level for fish. The chlorinated hydrocarbons may persist in the soil and contaminate run-off waters for several years following application, and hence are especially troublesome.

The two important factors determining whether or not biologically active organic compounds, such as pesticides, do cause major pollution problems are concentration and resistance to microbial breakdown. The quantity of pesticide chemicals found in water leaving agricultural areas is governed to a large part by chemical formulations, usage, and application rates. Chemical structure is a determining factor in resistance to biological degradation. The type and extent of chemical substitution appear to be the chief regulators of microbial response. Thus it has been found that the greater the extent of chlorine substitution, the harder the molecule, other factors being equal.

Phosphorus derivatives also have been found highly resistant to microbial attack while related carbon skeletons not containing phosphorous or chlorine are generally subject to rapid microbial degradation.

This paper also contains listings of comparative toxicities, pesticide carriers, solid diluents, emulsifiers, liquid solvents, synergists, and the common pesticides.

14. Ryckman, D. W. and Sproul, O. J., Significance of Trace Organics in Water Pollution. Journal Water Pollution Control Federation, Vol. 33, 11, p. 1188-1198 (November 1961).

The origin and significant characteristics of certain organic pollutants were determined. Data include amounts of organics by source, odor characteristics, and chemical and biological oxygen demand.

A lay-out for waste-water sampling illustrates a method for collection of material for analysis. Organic pollutants were successfully extracted from liquid wastes by a carbon filter technique with pH adjustment. Chloroform and alcohol soluble materials were extracted in appreciable amounts from all of the source samples. All of the organic material extracted had a significant odor potential, which could be decreased or increased depending on the type of organic material present. A series of curves illustrates the biochemical oxygen demand progression of chloroform-soluble organics.

15. Webb, Hubert J., Water Pollution Resulting from Agricultural Activities. Journal American Water Works Association, Vol. 54, 1, p. 83-88 (January 1962).

Animal wastes, pesticides, and fertilization practices have important effects on water to be subsequently used and made safe for human consumption. Application of weed killers, fungicides, nematode poisons, insecticides, and growth regulators is the major farm practice effecting degradation of water quality. The comparative toxicity of organic phosphorus and chlorinated hydrocarbon insecticides is given.

III CONSUMPTIVE USE, IRRIGATION REQUIREMENTS, "DUTY OF WATER"

The degree of water consumption by irrigated crops plays a major role in the salinity concentration and the volume of drainage water that leaves an irrigated area. Consequently, consumptive use data is also useful in determination or prediction of the volume of water to be diverted to a given area to satisfy crop requirements and to maintain a favorable salt balance in that area. Such determinations are necessary to insure the efficient usage of water and eliminate waste of waters in the arid west.

1. Fortier, Samuel, Evaporation Losses in Irrigation and Water Requirements of Crops. U. S. Department of Agriculture, Office of Experiment Stations, Bulletin No. 177, 64 p. (1907).

   This is a report giving the results of experiments undertaken for the purpose of determining the amount of water lost by evaporation from irrigated soils, and the extent to which these losses can be avoided by improvement of water application methods and by subsequent cultivation of the soil.

   The report gives quantitative statements of the losses of water, and calls attention to their magnitude with the idea of possibly extending irrigation areas where the water supply is limited.

2. Hammatt, W. C., Determination of the Duty of Water by Analytical Experiments. Transactions, American Society Civil Engineers, Vol. 83, p. 200-250 (1919)

   This paper presents a method used in the determination of the amount of water required for the growth of certain crops in situations where it is not practical to measure it directly. This method was devised by analyses of the requirements and by the separate experimental determination of the specific quantity required for the different parts which go to make up the whole use of water by the plant.

3. Consumptive Use of Water in Irrigation. Progress Report of the Duty of Water Committee of the Irrigation Division, Transactions, American Society Civil Engineers, Vol. 94, p. 1349-1377 (1928).

   This report proposes detailed definitions of the consumptive use of water in irrigation. It also calls attention to differences between the basic meaning of consumptive use and its application to the valley, farm, and project. The common difficulties in making a dependable determination of consumptive use are enumerated and briefly discussed. Observations of consumptive use of water in typical irrigated valleys of the West are reported.

4. Conklin, H., Discussion on Consumptive Use of Water in Irrigation. Transactions American Society Civil Engineers, Vol. 94, p. 1378-1382 (1928).

This is a presentation of consumptive use data from the San Gabriel Valley, California.

5. Bibliography of Water Requirements of Plants. Imperial Council of Agricultural Research, New Delhi, printed by the Manager, Government of India Press (1938).

A listing of 203 references is given on the subject.

6. Lowry, R. L. and Johnson, A. F., Consumptive Use of Water for Agriculture. Transactions American Society Civil Engineers, Vol. 107, p. 1243-1266 (1942).

Consumptive use is shown in this paper to possess a straight-line relationship in a number of adequately water irrigated valleys and humid watersheds representing a wide range in type of crops grown, elevation, climate, and latitude. This relationship holds true within narrow limits to accumulated daily maximum temperatures above the freezing level during the growing season. Factors responsible for deviations from the average consumptive use are discussed. Short descriptions of each area studied, with annual data summaries, are appended.

7. Criddle, W. D., Irrigated Crops. Transactions American Society Civil Engineers, Vol. 117, p. 991-1000 (1942).

Frequently large amounts of water consumed in an irrigated area can be saved or recovered by varying the crops grown. Ranges are given for the amount of water consumed by various types of vegetation under different climatic conditions in the United States. Alfalfa, for example, may consume 4.5 acre-feet of water per acre in the Salt River Valley of Arizona but only 1.5 acre-feet per acre in areas of Colorado. On the other hand, mature spring wheat will use about 1.4 acre-feet per acre wherever it is grown.

8. Erickson, John R., Consumptive Use of Irrigation Water in Lower Uncompahgre Valley. Colorado Water Conservation Board (July 1943).

This is one of a series of reports covering field investigations and analytical studies of the crop production and use and disposal of the water resources in the State of Colorado.

9. Blaney, H. F., Use of Water by Irrigated Crops in California. Journal American Water Works Association, Vol. 43, 3, p. 189-200 (March 1951).

This paper presents data on seasonal consumptive use of irrigation water by various crops in several California counties for consecutive years. A discussion of methods of calculating consumptive use is also presented.

10. Blaney, H. F., Consumptive Use of Water. Proceedings American Society Civil Engineers, Vol. 77, Separate No. 91, 19 p. (October 1951).

One of the basic needs of consumptive use data is in estimating the overall water requirements of irrigation projects and in the calculation of the quantity of water required for crop production on individual farms within a project. Irrigation efficiency and the amount of usable summer precipitation are determinants in the volume of water required for irrigation. In some irrigated areas, it is necessary to estimate irrigation requirements for each crop at the point of delivery to each field. These estimates may be made by dividing the consumptive use less precipitation by field irrigation efficiency. The amount of water that should be delivered to the farm headgate may be estimated by making an allowance for farm-lateral loss from the headgate to the field.

11. Tomlinson, Byron R., Estimate of Water Requirements of Crops. University of Wyoming Bulletin No. 303, 27 p. (1951).

The Bulletin presents a method of computing the amount of applied water necessary to satisfy given crops' water requirements in Wyoming. Tables of monthly climatic data assembled by drainage basin within Wyoming are used.

12. Molenaar, Albert, et al, Estimates of Consumptive Use and Irrigation Requirements of Crops in Washington. Washington Agricultural Experiment Station, Circular No. 201, 20 p. (September 1952).

Seasonal consumptive use estimates are given for each of eight irrigated crops, by area, in the State of Washington. Total consumptive use and total consumptive use minus rainfall data are also shown.

13. Fuhriman, E. K. and Criddle, W. D., Consumptive Use of Water Studies Provide Basis for Division of the Waters of the Colorado River. Farm and Home Science, Vol. 13, 4, p. 86-87 and 100 (December 1952).

This is a report of studies conducted in Ashley and Fernon Valleys of Utah to determine the consumptive use of water by various types of vegetation in these areas. The results show that even sparse native vegetation consumes nearly 12 inches per year. Heavier growths of native vegetation in wet areas use up to 50 inches of water per year. Alfalfa and irrigated pasture have a consumptive use of 33 inches per year, while corn and small grains use about 22 inches per year.

14. Blaney, H. F., Definitions, Methods, and Research Data. Transactions American Society Civil Engineers, Vol. 117, p. 948-968 (1952).

This paper discusses consumptive use with special reference to definitions, methods, and research results. The procedure for determining consumptive use of water in valley areas from irrigation, climatology, and other data is presented. The results of experimental measurements of evapotranspiration by crops and by natural vegetation are presented.

15. Lowry, R. L., Discussion of Consumptive Use in the Rio Grande Basin. Transactions American Society Civil Engineers, Vol. 117, p. 1014-1020 (1952).

The paper brings out the fact that there is a point beyond which salt concentration in irrigation drainage waters cannot be tolerated permanently. This limits the extent of irrigated acreage that can be developed unless reductions in other water uses are made.

16. W. D. Criddle, Consumptive Use of Water and Irrigation Requirements. Journal Soil and Water Conservation, Vol. 8, 9, 207-212 (September 1953).

The author presents nomographs for the quick determination of monthly consumptive-use rates, peak-daily-use rates and required flow rates for use in the design of irrigation systems.

17. Estimated Water Requirements of Crops in Irrigation Areas of Montana. Montana State College Agricultural Experiment Station Bulletin No. 494, 23 p. (1953)

The report lists estimated water requirements of principal crops and estimated peak monthly consumptive use of water by individual crops in various areas of Montana. Coefficients are used in making the estimations. Also included are measured consumptive use data of principal crops in irrigated areas outside Montana.

18. Lull, Howard W., Evapo-Transpiration: Excerpts from Selected References. Vicksburg Infiltration Project, Southern Forest Experiment Station, U. S. Forest Service, Occasional Paper No. 131 (1953).

This paper contains excerpts from 76 papers on the subject.

19. Barrett, Willis C. and Milligan, Cleve H., Consumptive Water Use and Requirements in the Colorado River Area of Utah. Utah Agricultural Experiment Station, Special Report No. 8, 28 p. (1953).

This paper describes a study of unit consumptive use rates in the Ashley and Ferron Valleys, Utah for various irrigated crops. The study showed that the total annual consumptive use for native vegetation and agricultural crops is considerably more than the streamflow depletion caused by man's activities alone. Most of the normal rainfall falling on the valley floors plus some surface and underground seepage was consumed by the native vegetation of the area. Thus the maximum possible streamflow depletion attributable to the activities of man is the seasonal consumptive use of the cropped acreages, less the effective summer precipitation.

This study indicates that consumptive use coefficients in common usage may need to be increased for use in eastern Utah.

20. Evapo-Transpiration Measurements in Western United States. de l'Association Internationale d'Hydrologie, Vol. 38, p. 150-160 (September 1954).

Field methods for the determination of water use are described and results of such measurements of irrigated crops and natural vegetation in the western United States are given. A method for determining evapotranspiration in areas where no measurements are available is also described.

21. Blaney, H. F., Consumptive Use Requirements for Water. Agricultural Engineering, Vol. 35, 12, p. 870-873 (December 1954).

The application of evapotranspiration data in determining available water supply in drainage basins is considered. Summaries of four studies are given to illustrate the use of the data.

22. Harrold, L. L., Evapo-Transpiration Rates for Various Crops. Agricultural Engineering, Vol. 36, 9, p. 669-673 (September 1955).

Rates of evapotranspiration for different crops vary throughout the growing season. This paper presents data showing that peak-use rates differ as much as 0.14 inches per day from the average monthly values.

23. Thornwaite, C. W. and Mather, J. R., The Water Balance. Drexel Institute of Technology, Laboratory of Climatology, Canterton, N. J. 104 p. (1955).

This report attempts to show the development of the water balance concept and to demonstrate its usefulness in understanding

moisture relationships. The first part of the report includes a discussion of the problems and limitations involved in attempts to measure evapotranspiration rates or in attempts to compute it from climatic data.

The second part of the report includes a discussion of the application of the various elements of the water balance to different areas of research. Checks on the validity of the results have shown that very reasonable values of soil moisture storage and moisture surplus and deficit have resulted from the use of the procedure. A bibliography of papers dealing with potential evapotranspiration and water balance is included.

24. Palmer, R. A., Estimating Irrigation Requirements. Agricultural Engineering, Vol. 37, 11, p. 759 (November 1956).

This paper introduces a technique for analyzing data which may be effective in establishing irrigation water requirements. The technique is based on a study of rainfall records and the estimate of soil moisture deficiencies.

25. Goodrich, R. D., Methods of Determining Consumptive Use of Water in Irrigation. Transactions American Society Civil Engineers, Vol. 122, p. 806-819 (1957).

This paper draws attention to some of the early investigations of the duty of water in irrigation. With the acquisition of knowledge in this field, attention became focused on the consumptive use of water, i.e., evapotranspiration. The author describes the standard methods of the determination of rates of consumptive use and examines the utilization of the results thus obtained to measure farm and valley use of water.

26. Criddle, W. D., Methods of Computing Consumptive Use of Water. Proceedings American Society Civil Engineers, Vol. 84, IR 1, 27 p. (January 1958).

Consumptive use of water is a concept and term that has become widely accepted in the fields of water supply and hydrology. The author discusses several of the more commonly used methods for determining consumptive use requirements of crops. Charts and certain data that may simplify the application of the described methods is included.

27. Consumptive Use and Irrigation Water Requirements of Milford Valley, Utah. U. S. Dept. of Agriculture, Agricultural Research Service Publication No. 41-14, 45 p. (April 1958).

The publication includes data from Milford Valley on: acres irrigated, measured consumptive use by the soil-moisture-depletion method, amounts of pumped ground water, and computation of annual consumptive use rates for various crops, 1951-1954. Information is also given on measured seasonal consumptive use rates from various areas of the West, water application efficiency tests, and annual consumptive use computed from

inflow-outflow data and by the integration method.

28. Blaney, H. F., Monthly Consumptive Use Requirements for Irrigated Crops. Proceedings American Society Civil Engineers, Vol. 85, IR 1 (March 1959).

This paper presents data on measured monthly rates of consumptive use of water for various irrigated crops in western United States. A procedure of determining monthly consumptive use requirements from climatological data for areas where measurements of water use are not available is described.

29. Rijtema, P. E., Calculation Methods of Potential Evapotranspiration. Institute for Land and Water Management Research. Technical Bulletin No. 7, Netherlands (1959).

The paper presents a review of the various methods that have been suggested for the calculation of potential evapotranspiration.

30. Munson, Wendell C., A Method for Estimating Consumptive Use of Water for Agriculture. Proceedings American Society Civil Engineers, Vol. 86, IR 4, p. 45-47 (December 1960).

This paper presents data on measured rates of consumptive use and estimated consumptive use determined by various formulas. A procedure is described for determining monthly and annual water requirements on a project basis from climatological data. The simple method for estimating consumptive use of water for agriculture is termed the Precipitation-Evaporation Index Method. This simple method of estimation was devised because of the lack of necessity of knowing the exact needs of plants for project planning when such factors as application efficiencies, cropping practices, delivery losses, and many other factors exert a far greater range in divergence.

31. Hamon, W. Russell, Estimating Potential Evapotranspiration. Presented at Boston American Soceity Civil Engineers' Convention, Oct. 10-14 (1960).

The turbulent-transport and energy-balance concepts have been the bases for analytical methods of estimating potential evapotranspiration. In this paper, an empirical formula has been formulated correlating the temperature function and adjusting for length of day. This approach provides a simple procedure for estimating potential evapotranspiration. The results of using this procedure are compared with those obtained by applying a more complex procedure.

32. Daniels, L. L., Consumptive Use of Water by Major Crops in Texas: Texas Board Water Engineers (1960).

Estimates of water consumption have been made for different crops at various locations by months, by season, and annually.

33. Blaney, H. F., Determining Irrigation Requirements from Consumptive Use Water Rates. Transactions 5th International Congress of Agricultural Engineers, Brussels, Belgium, Vol. 1, p. 292-304 (1960).

Measurements of consumptive use for various irrigated crops are presented in this paper. A formula was developed for estimating consumptive use from climatological data. The determination of irrigation requirements from irrigation efficiencies and rates of consumptive use is shown for various crops.

Disregarding the lesser factors, consumptive use rates are a function of available moisture, temperature, and length of day. A monthly consumptive use constant is obtained by multiplying the monthly percent of daylight hours of the year times the mean monthly temperature.

34. Water Requirements of Crops. American Society Agricultural Engineers, Special Publication No. SW-0162 (1962).

A publication containing five papers pertinent to water requirements of crops. These papers are: (1) "Methods of Estimating Evapotranspiration of Water by Crops," - Norman A. Evans; (2) "Estimating Future Water Requirements of Crops," - Sterling A. Taylor; (3) "Weather Factors that Influence Water Requirements of Crops," - W. O. Pruitt; (4) "Influence of Soil Factors on the Water Requirements of Crops," - J. F. Powers and D. D. Evans; (5) "Irrigation Efficiency as It Influences Water Requirements of Crops," - Glen H. Cannell.

IV DRAINAGE, SALT BALANCE

Return flows draining from an irrigated area represent that portion of the diverted irrigation water that is not lost to evapotranspiration in an area of stabilized ground-water levels. These return flows contain salts whose quantity and concentration have been increased by evapotranspiration, leaching, and ion-exchange. The salt concentration in the return flows is further increased by efforts to maintain a favorable salt balance; i.e., have a larger quantity of salts leaving the irrigated area than enters it in the diverted water.

1. Wright, C. C., Salt Drainage from Irrigated Land. Surface and Sub-Surface Waters of the Yakima and Klamath Reclamation Project. State College of Washington, Bulletin No. 228 (July 1928).

   This is a report of the results of a study conducted on the Yakima and Klamath Reclamation Project. Extensive analyses of irrigation supply water, soil water, and drainage water were performed. One of the major conclusions resulting from analysis of the acquired data is that the drainage waters from normal productive land are as salty as the drainage from alkali areas. This indicates that at least a portion of the drainage waters in some areas of the project comes from sources other than circulation through the upper layers of soil.

2. Willis, R. H., Return Water, North Platte River, Nebraska. Transactions American Society Civil Engineers, Vol. 94, p. 328-332 (1930).

   The mean annual flow of the North Platte River since 1900 at North Platte, Nebraska is 2,294,000 acre-feet. Approximately 1,200,000 acre-feet were diverted from the river flow during each of the 1925, 1926, and 1927 seasons between Whalen, Wyoming and Bridgeport, Nebraska for application to the cropped lands in the basin. About 65 percent of the diverted water came back into the stream as return flow. Probably the major portion of the return water entered the North Platte River through deep percolation.

3. Murphy, D. W., Drainage Recovery from Irrigation. Transactions American Society Civil Engineers, Vol. 94, p. 333-337 (1930).

   Frequently it is possible to recover a portion of the applied irrigation water that sinks below the zone of plant growth and is wasted. This recovery can be effected through proper drainage. The character of the underground formation largely determines the recoverable quantity of water.

The feasibility of recovering this waste by means of drainage depends upon the cost involved in such drainage and the value of the water at its collection or discharge point. In areas where drainage must occur to prevent water-logging and alkalinization of the soil, the value of the recovered water represents a net gain. For example, in the Salt River Valley of Arizona the water drained to protect the soil and growth of crops is a definite asset. It is used to supplement the gravity supply in dry years and is also sold for use on adjacent lands.

4. Meeker, R. I., A Discussion on Return Flow from Irrigation. Transactions American Society Civil Engineers, Vol. 94, p. 338-340 (1930)

Consumptive-use determinations and return-flow measurements of irrigated lands go hand in hand and will play a large part in the future use of rivers for irrigation. If return-flow waters are not allowed for in studies and estimates of river supplies, any forecast of acreages which may be opened to irrigation agriculture will be restricted. Irrigation return flows usually set up slowly and progressively. Dependent on soil conditions, topography, and water usage, they may require from ten to twenty years to reach a condition of stability.

5. Drainage of Irrigated Lands. Report of the Committee of the Irrigation Division, Transactions American Society Civil Engineers, Vol. 94, p. 1425-1447 (1930).

The following pertinent paragraph is excerpted from this report:

"Colorado River - The average of samples from each irrigation at the Experiment Farm of the U. S. Department of Agriculture at Bard, near Yuma, Arizona shows the total solids in solution for the year's average to vary between 805 and 997 ppm (Oct. 1922 to Sept. 1927). Weighted by flow - as would occur when a stream is completely reservoired - the average yearly salinity will vary from 544 to 697 ppm. For considerable periods, during low flow, the salinity has exceeded 1000 parts, reaching in excess of 2400 parts in October, 1924. Water of this average quality (except for slight changes due to alkali absorbed from the channel below Yuma) has been used in the Imperial Valley for 25 years without damage to well-drained land. Lands subject to seepage or high groundwater have been seriously damaged."

6. Walker, A. W., Drainage of Irrigated Lands. Civil Engineering, Vol. 8, 11, p. 733-734 (November 1938).

One of the most serious problems in arid regions where irrigation is necessary for crop growth is the alkali problem, i.e., the accumulation of soluble salts in the soil that destroy fertility.

In some cases where alkali has accumulated, a prolonged period of leaching will correct the situation. In other cases, application of chemicals has been effective. Very often a system of drainage may be required in addition to induce downward percolation of water through the soil.

7. Scofield, C. S., Salt Balance in Irrigated Areas. Journal of Agricultural Research, Vol. 61, p. 17-39 (July 1939).

The salt balance for the irrigated lands below Elephant Butte Reservoir on the Rio Grande River in Texas is calculated. The following summaries are presented: bicarbonate inflow 100,000 tons; outflow 37,000 tons; chloride inflow 70,000 tons, outflow 234,000 tons; sulfate inflow 240,000 tons, outflow 138,000 tons; calcium inflow 80,000 tons, outflow 50,000 tons; magnesium inflow 16,000 tons, outflow 12,000 tons; alkali bases inflow 111,000 tons, outflow 165,000 tons. The calculations indicate a favorable salt balance in that calcium salts were precipitated in the soil and sodium chloride was removed from the soil. However, this Project also represents a striking example of stream pollution by irrigation residues.

Another example of a favorable salt balance is given--the Yuma Valley area; and an example of an unfavorable salt balance--the Imperial Valley. When the proposed Colorado River developments are completed, 8 or 9 million acre-feet passing Lee's Ferry will carry the same tonnage of salts as the 16 million acre-feet of 1940.

8. Wilcox, L. V. and Nelson, Carl E., The Ground Water and Salt Balance Conditions of The Sunnyside Valley Irrigation District for the Period March 1 to October 31, 1944. U. S. Dept. of Agriculture, Roubidoux Laboratory Report (March 7, 1945).

The data show that, for the period March 1 to October 31, 1943, the net volume of irrigation input was 167,931 acre-feet containing 18,785 tons of total dissolved solids while the output was 68,033 acre-feet containing 34,682 tons of total dissolved solids. For March 1 to October 31, 1944, the input was 164,000 acre-feet containing 17,784 tons of total dissolved solids and the output was 62,456 acre-feet containing 30,423 tons total dissolved solids.

The output of sulfate was many times as great as the input while the silica output was less than the input. The output of nitrate exceeded the input several fold. Among the eleven constituents determined there was only one for which the output tonnage was less than the input (silica). The fact that the output of nutrient constituents, potassium, nitrate, and phosphate exceeds the input does not have any serious implications regarding the sustained productivity of the soil of the district because the quantities involved are small and an excess of output of these constituents is to be expected where the salt balance is favorable.

9. Tabor, C. C. Drainage and Salt Balance in Relation to Imperial Irrigation District. Proceedings of Conference on Quality of Water for Irrigation Proceedings, Water Research Center, University of California, Vol. 14, p. 760-784 (January 1948).

The purpose of a drainage system is to remove accumulated salts from the root zone and keep the water table at a suitable depth below the land surface so as not to interfere with crop growth.

In an irrigation project, the salt content of the discharge water must at least equal the amount of incoming salt. This salt must be removed from the root zone area of the soil by drainage.

10. Wilcox, L. V., Salt Balance Conditions of Reclamation District No. 1500 in Sutter Basin, California for the Year Ending Dec. 31, 1947. U. S. Department of Agriculture, U. S. Salinity Laboratory Research Report No. 26 (April 1948).

The total salt concentration of the drainage water from this Project was approximately five times that of the applied irrigation water. The sodium concentration in the drainage water was eight times that in the irrigation water and the chloride was twenty-two times. The irrigation input for the year amounted to 299,300 acre-feet of water containing 50,881 tons of total dissolved solids. The drainage output for the same period amounted to 152,110 acre-feet of water containing 126,251 tons of total dissolved solids. The difference in total dissolved solids amounts to 75,370 tons. The salt balance in this district is favorable. This is not unexpected, considering the very good drainage system and the type of agriculture practiced in this district.

The large quantity of salt in the output as compared with that in the input indicates a source of salt, in large quantity, within the irrigation system in this case, presumably, an artesian aquifer containing saline water.

11. Gardner, W. R. and Brooks, R. H., A Descriptive Theory of Leaching. Soil Science, Vol. 83, p. 295-304 (1957).

In this paper equations are derived to describe the process of leaching of soluble salts from soils. It is assumed that the flow process, rather than diffusion, is responsible for the diffuse boundary between the leaching water and the soil solution and for the subsequent salt removal.

12. Evans, N. A., Reclamation and Drainage of Saline - Sodic Soils in the Upper Colorado River Basin. International Committee on Irrigation, 4th Congress on Irrigation and Drainage, Vol. 2, p. 13-113 (1960).

In the Upper Colorado River Basin, ground-water and salt problems have resulted from irrigation development. Extensive studies have been made to determine what remedial measures can be taken for the drainage and reclamation of the Grand Valley of Colorado.

It was found that pumping was feasible to accomplish drainage since a good aquifer is present at shallow depth. The ground-water hydrology was studied to determine the drainage load of the valley. The drainage load was found to be greatly in excess of the natural drainage capacity of the valley soils.

Experiments were conducted to determine feasible methods of reclaiming the soils. Leaching with six feet of water was found to be suitable for reclamation of a four-foot soil zone. In the fourth year it is desirable to add 50 percent extra irrigation water to maintain a safe salt level.

13. Hurley, Patrick A., Predicting Return Flow from Irrigation. U. S. Bureau of Reclamation, Report No. TM 660 (August 1961).

An analytical method of computing the return flow from an irrigated area is described in this publication. The method makes use of the distance between drainage channels, the hydrologic properties of the aquifer underlying the irrigated area, and percolation to ground water to compute the resulting return flow.

Studies made by the Water Resources and Utilization Section of the Hydrology Branch, Division of Project Investigations calculated the monthly return flows for the Mesilla Valley of the Rio Grande Project using this procedure. The calculated return flows compared favorably with the measured quantities.

V WATER USE DATA, STATISTICS

Water-use data by geographical or political sub-divisions is indispensable in any attempt to ascertain the relationship of total demand to supply in the water economy of an area. This is a primary consideration in the budgeting of the local water resource for efficient and economical assignation.

Water-use data also may be used in extrapolating future water needs and as a base of determination of water quality objectives in a water pollution control program.

1. Use of Water on Federal Irrigation Projects. U. S. Bureau of Reclamation, 79 p. (August 1952).

   This report by the U. S. Bureau of Reclamation includes data from all its Projects on the subjects of climate, soils, topography, crops, projects works, and irrigation practices.

   The purpose of this preliminary report is to:

   a. Summarize in a uniform manner the data pertaining to the use of of water on Bureau Projects since 1927.
   b. Discover the deficiencies in existing data.
   c. Recommend practical procedures for obtaining additional water requirement information needed for planning of future projects.

2. Water Utilization and Requirements of California. California Water Resources Board, Bulletin No. 2, Vol. 1, 227 p. (1955).

   This report presents results of a comprehensive analysis of present and probable ultimate water use in California for irrigation and for agriculture, municipal, industrial, and other uses. Estimates of the gross water requirements for regions as well as for the State are given.

3. Picton, Walter L., Water Use in the United States, 1900-1975. U. S. Dept. of Commerce, Business and Defense Services Administration, Business Service Bulletin No. 136, 6 p. (1956).

   Daily average water use in the U. S., by years, for irrigation, public water supplies, and self-supplied water is presented in this bulletin. The self-supplied uses include domestic, industrial, and steam electric power.

4. Woodward, D. R., Availability of Water in the United States with Special Reference to Industrial Needs by 1930. Armed Forces Washington Industrial College, 74 p. (1957).

The data in this publication include typical water use and minimum requirements by industry; the water use for industrial, domestic and agricultural needs on a regional basis; the population served by public water systems and the estimated consumption, 1955 and 1980; and the relationship between supply and demand for 1955 and estimates for 1980.

5. Development of Water and Land Resources of the Arkansas-White-Red River Basins. 85th Congress, 1st Session; Senate Document No. 13 (1957).

Industrial and nonindustrial water-use data for Wichita, Kansas are shown for every 10 years from 1950 to 2010. Acreage irrigation data for rice and other crops, and the source of water are given for a number of systems. Water use data for some projects are given.

6. Bohanan, Luther B., Irrigation Use of Water. Journal American Water Works Association, Vol. 50, 3, p. 310-314 (1958).

For 28 humid states and for the United States as a whole, data are given on acreage irrigated, 1949-1954; rate of irrigation increase, 1949-1954; and acreage estimates for 1960-2000.

7. Water Resources Activities in the United States. U. S. Senate, Select Committee on National Water Resources, 86th Congress, 1st Session, Committee Print 1 (1959).

Included in this report are data on: fresh and saline water withdrawals by source for the United States; consumptive and non-consumptive use of water by irrigation; industrial and public supplies; industrial water uses, fresh and saline; regional water usage; water requirements for a number of crops and industries; water use for electric power; water demand for 1950, 1960, 1970, 1980; and major water problems.

8. Estimated Water Requirements for Agricultural Purposes and Their Effects on Water Supplies. U. S. 86th Congress, 2nd Session, Committee Print 13, 34 p. (1960).

Data are given to show the projected increase in irrigated acreage from 1957 to 1980 and for the year 2000. The estimated effect of agricultural activities on annual water supply for 1980 and 2000 are given.

9. Water Use in the United States, 1900-1980. U. S. Dept. of Commerce, Business and Defense Services Administration, 6 p. (1960).

The data given in this paper include the estimated water use by source for irrigation and by years for the United States.

10. Farm and Home Science. Utah State University Agricultural Experiment Station, 119 p. (1960).

This article includes a section on present water uses and future requirements in 1980. Problems of development for future needs are also discussed.

11. Water Supply and Demand. U. S. Senate, Select Committee on National Water Resources, U. S. 86th Congress, 2nd Session, Committee Print 32, 131 p. (1960).

The data given in this report include withdrawal uses and losses for agriculture, by region, for the year 1954, and projected to 1980 and 2000; distribution of required flow for various uses; present available supply; required storage to insure selected dependable flows; and the ratio of maximum obtainable water supply to minimum flow requirements.

12. Irrigation in Texas in 1958. Texas Board of Water Engineers Bulletin No. 6018, (1960).

Data is presented in this bulletin to show the number of acres irrigated and the amounts of surface and ground water applied in the State of Texas. The data is given by river basin, county, and soil conservation district. The acreage and volume of water used for the production of seventeen different crops is given by water source and by county.

13. Water Resources Activities in the United States. Views and Comments of the States. U. S. Senate, Select Committee on National Water Resources, U. S. 86th Congress 2nd Session, Committee Print 6, p. 228-254 (1960).

Data on the use of surface and ground water for municipal, industrial, rural non-agricultural, and for irrigation purposes is given in this report.

14. Mackichan, K. A. and Kammer, J. C., Estimated Use of Water in the United States 1960. U. S. Geological Survey, Circular No. 456, 26 p. (1961).

The amount of water withdrawn and the amount consumed is reported in this paper for each of the fifty states, Puerto Rico, Virgin Islands and twenty-one regions. Data are presented in five categories: public supplies, self-supplied industrial, self-supplied rural, irrigation, and water power. The waters are classified as fresh or saline and by source.

15. Crop Report and Related Data. U. S. Bureau of Reclamation, Division of Irrigation and Land Use, 192 p. (1961).

An annual crop census report is prepared on each operating project that receives irrigation water from facilities constructed by the Bureau. This 1961 report is the 56th consolidated report of the results of these census published by the Bureau.

The report is a statistical compilation of type of crops, yield, acreage, etc., data for all Bureau projects since the inception of the Bureau. (Published annually).

16. Statistical Appendix to Crop Report and Related Data. U. S. Bureau of Reclamation, Division of Irrigation and Land Use, 192 p. (1961).

The Statistical Appendix, containing information needed primarily for administrative use in the Bureau, is available for those wishing detailed information on specific projects. It includes regional and project data on acres, yield, production, and gross value of crops grown, land utilization, water distribution, status of reclamation lands, and other related subjects. (Published annually).

VI OTHER

Reference items which do not readily correspond to the five previous sections are included in this section.

1. Hutchins, W. A., Policies Governing the Ownership of Return Waters from Irrigation. U. S. Dept. of Agriculture, Technical Bulletin No. 439, 48 p. (1934).

   This bulletin reports the results of a study conducted in thirteen of the western states. The study was conducted to secure information on the extent of return flow use for irrigation, on the nature of conflicts over the right to its use, its effect on irrigation development, the nature and implementation of policies governing the reuse, and on the necessity for further formulation of policies governing the reuse of irrigation return flows.

2. Theron, J. J., Alkali and Irrigation Studies with Citrus Trees in the Sundays River Valley. University of Pretoria Publication Series 1, Agricultural No. 40, 41 p. (1937).

   A severe and sudden defoliation of certain varieties of citrus trees occurred due to pollution of the irrigation water with highly saline seepage water. The salts adversely affected the physical and chemical properties of the soil, causing water movement in the soil to become so sluggish that the rate of transpiration of the citrus trees was greatly diminished. Water seepage into the soil was retarded and the water-holding capacity was greatly lowered so that a considerably larger quantity than normal of the water applied was wasted through surface evaporation and runoff.

3. Irrigation--A Selected Bibliography. U. S. Dept. of Agriculture, Bureau of Agricultural Engineering (1938).

   This is a bibliography compiled from the catalogues in the U. S. Department of Agriculture and Library of Congress supplemented by material from the Engineering index, Agricultural index, and Industrial Arts index. It includes references to books, periodicals, and publications through 1937.

4. Larson, Carl A., Reclamation of Saline Soil in the Yakima Valley, Washington. Washington Agricultural Experiment Station, Bulletin No. 376, p. 5-39 (1939).

   This paper describes a saline soil reclamation project in the Yakima Valley. About two-thirds of the soluble salts were removed from the surface foot of the soil by two periods of irrigation. Precipitation caused a marked variation in salt content of the surface foot of soil.

5. Hayward, H. E. and Migistad, O. C., The Salt Problem in Irrigation Agriculture. U. S. Dept. of Agriculture, Misc. Publication No. 607, 27 p. (August 1946).

This publication describes the areas of research conducted by the U.S. Regional Salinity Laboratory on the salt problem in irrigation agriculture.

6. Gardner, Willard; Garder, J. H. and Lauritzen, C. S., Rainfall and Irrigation in Relation to Soil Erosion. Utah Agriculture Experiment Station Bulletin No. 326, 12 p. (1946).

This is a report of laboratory experimants showing the rate at which erosion occures with different percent slopes. The experimnts are briefly discussed with reference to various sizes of soil particles, irrigation practices, and rainfall.

7. Land Classification Report. Wellton-Mohawk Division, Gila Project, Ariz. U. S. Bureau of Reclamation, 69 p. (July 1948).

This detailed land classification of 148,585 acres in the Wellton-Mohawk area, Gila Project, was made to obtain the basic data needed to determine the most feasible area of 75,000 acres as limited by Public Law 272, for irrigation with Colorado River water.

8. Symposium on Water for Irrigation Use. Chemical and Engineering News, Vol. 29, 11, p. 990-994 (March 1951).

This symposium was presented by the Division of Water, Sewage, and Sanitation Chemistry at the 115th Annual Meeting of the American Chemical Society, San Francisco, California, March 30, 1949.

The article is a short review of presentations made at the symposium. These presentations are: (1) "Trends of Irrigation Development in the United States;" (2) "Quality of Irrigation Water;" (3) "Quality of Irrigation Waters of the West;" (4) "Influence of Irrigation Waters on Soils;" (5) "Effect of Irrigation Water on Plants."

9. Saline and Alkali Soils. U. S. Dept. of Agriculture, U. S. Salinity Laboratory, Agriculture Handbook No. 60 (1954).

Saline and alkali soil conditions reduce the value and productivity of considerable areas of land in the United States. It is the purpose of this handbook to summarize information that will be useful, particularly to agricultural workers for the diagnosis and improvement of saline and alkali soils.

The term "alkali soil" is used in this handbook to refer to soils that have a high exchangeable-sodium-percentage; and "saline soil" is used to describe soils whose saturation extract exhibits a high degree of electrical conductivity.

The handbook is intended primarily as a practical guide for those who are confronted with soil, plant, and water problems involving salt and alkali. The first five chapters provide a basis for the evaluation and interpretation of measures. Chapters 6, 7, and 8 give the procedures and measuring methods which the Laboratory has used in the diagnosis and improvement of saline and alkali soils.

10. Darab, K., Secondary Salinization of Irrigated Soils of the Hungarian Lowlands. Pochvovendenic No. 11, p. 41-47 (1955).

Soil waters from irrigated soils were analyzed for sodium, magnesium, potassium, calcium, sulfate, chloride, and basicity. The analyses show that in some cases soils under irrigation are desalinized and adjacent non-irrigated soils are salinized.

11. Szabolcs, Istvan and Darab Katalin, Dynamics of Soluble Salts in Irrigated Soils. Agrokemia 'es Talajtan Vol. 4, p. 251-264 (1955).

Investigations were made of the periodic changes of salt content of irrigation water, ground water and of the soil at various depths. These investigations showed that knowledge of static conditions based on average samples is not sufficient to characterize salt conditions in an irrigated soil. Salt movement within the soil depends on many factors: the level and chemical composition of the ground water, the irrigation water quality, and on general conditions as seasons, temperature, and precipitation. A definite periodicity was observed in respect to the amount of soluble salts, their quality, and their distribution at various levels. This periodicity was observed in the ground water irrigation water and the soil itself.

12. Amemiya, H., Robinson, C. W., and Cowley, E. W., Reclamation of a Saline-Alkali Soil in the Upper Colorado River Basin. Soil Science Society of America, Vol. 20, 3, p. 423-426 (July 1956).

An experiment was conducted to determine if it were feasible to reclaim an unproductive saline-alkali calcareous soil (Billings silty clay loam) in the Upper Colorado River Basin in the area of Grand Junction, Colorado. Leaching applications materially decreased the amounts of soluble salts and exchangeable sodium in the soil. The decrease was a function of the amount of leaching water used. From four to six feet of water were necessary to reclaim the soils to a depth of fifty inches.

13. Zinover, S. I., Desalting and Utilizing Salty Spots in Irrigated Soils. SSR No. 2, p. 47-52 (1956).

Salt spots in soil can be desalted effectively by washing with water in quantities of 30 percent to 40 percent of the natural soil water.

14. Madenor, D. K., Secondary Salination of Soil and Restoration of Its Fertility in the Upper Delta of the Ural River. SSR 12, No. 8, p. 44-52 (1956).

Precipitation causes a secondary salinity of the soils in this region predominantly composed of sodium chloride, sodium, magnesium chloride, magnesium sulfate, calcium chloride and sulfate ions. The addition of gypsum is not effective in desalting but thorough irrigation is a possible desalting method. Mineral fertilizers and manure are effective when used after deep irrigation.

15. Purvis, E. A. and Brill, G. D., Brackish Water to Irrigate Some Crops. New Jersey Agriculture Vol. 39, 1, p. 11-13 (1957).

Fresh water and mixtures of fresh water with up to one-half salt water were used to irrigate a number of crops. The results of these studies show that one inch per acre applications of water containing up to 5000 mg/l total dissolved salts can be used safely for irrigation of the crops tested.

16. Nelson, H. T., Upstream Irrigation Impact on Columbia River Flows. Proceedings American Society Civil Engineers, Vol. 85, IR 1, p. 1-12 (March 1959).

This paper presents an analysis of historic Columbia River flows at The Dalles to show the magnitude of peak flow reductions and low flow increases caused by upstream irrigation activities. Irrigation regulations may result in a low flow increase up to 12 percent as a result of 8500 irrigated acres upstream of The Dalles by the year 2010.

17. Fine, L. O. et al, A Study of the Sodium Adsorption Ratio and Residual Sodium Carbonate Concepts of Irrigation Waters as They Affect Exchangeable Sodium Under Semiarid Conditions. Proceedings of Soil Science Society of America, Vol. 23, 4, p. 263-266 (July-August 1959).

In field tests conducted in an area of about 15 inches annual rainfall, the highest exchangeable sodium level observed in the soil was two percent less than that predictable from the irrigation water. In greenhouse tests, however, the residual sodium carbonate caused accumulations of exchangeable sodium greater than those predictable from the irrigation water.

18. Quality of Surface Waters for Irrigation, Western United States, 1958. U. S. Geological Survey, Water Supply Paper No. 1575, 177 p. (1962).

This publication comprises the eighth annual compilation of data for eighty-one irrigation network stations in operation west of the Mississippi River and is composed of chemical analyses, physical

measurements and discharge. This report represents continuing comprehensive information of the chemical quality of surface waters used for irrigation and of the changes resulting from irrigated land drainage.

19. Ludwig, H. F., Gram, A. L., and Feeney, J. L., Pollution - Urban vs. Rural in Imperial Valley Waters-Parts I and II. Water and Sewage Works, Vol. 108, 7 and 8, p. 251-254 and p. 308-314 (July and August 1961).

This is a report of a sanitary survey of irrigation drainage waters. A discussion is presented of the use of irrigation wastewater for sewage disposal and recreational use at the terminal of the drainage basin, the Salton Sea.

20. Silin-Bekchurin, A. I., Salinity Problems in the Arid Zones. Conditions of Formation of Saline Waters in Arid Zones. Arid Zone Research No. 14, p. 43-47 (1961).

Experiments were conducted to determine the occurrence of alkalization formation in saline clayey loams. Solutions were obtained from successive filtrations which showed how the chemical composition of the solutions changed.

21. Irrigation on Western Farms: U. S. Dept. of Agriculture, Information Bulletin No. 199 (1959).

This publication presents a general discussion of irrigation for the lay reader. The following topics are included: soil, methods of irrigation, conveyance and control of irrigation water, preparation of land for irrigation, efficient use of irrigation water, and maintenance and land improvement.

22. Evaporation from the 17 Western States: U. S. Geological Survey, Professional Paper 272-D, 97 p. (1962).

The gross annual evaporation from water surfaces was estimated for the 17 States lying wholly or partly west of the 100th meridian. The evaporation in each subdivision of these States was computed as the product of the local evaporation rate times the water-surface area of the bays, lagoons, reservoirs, lakes, ponds, and streams within the subdivision.

Maps and tables present the estimated water-surface areas and the amounts of evaporation, subdivided by States and by principal river basins. For the 17-State area, the average annual evaporation is estimated as 23,641,000 acre-feet for fresh water areas and 17,565,000 acre-feet for salt water areas.